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Data for the acoustic design of studios

by

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(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

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FOREWORD

This is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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DATA FOR THE ACOUSTIC DESIGN OF STUDIOS

SUMMARY

This monograph is intended as a guide to the use of sound absorbing materials for the control of reverberation time in sound and television studios. It comprises data on sound absorption coefficients, preferred reverberation times of studios, and a table allowing easy evaluation of the function $-\log_e(1 - \bar{a})$ (required in Eyring's formula for the calculation of reverberation time).

1. Introduction

The coefficients listed in the tables were mainly determined by reverberation room measurements in the BBC Research Department. A few, including most of the 'Structural Coefficients' in Section A and many of the figures in Section D, were derived from analysis of reverberation time measurements in BBC studios. The remainder are taken from the literature. These are marked with asterisks; to make the tables as simple as possible the sources are not stated but nearly all are quoted from Bruel,[1] Knudsen and Harris,[2] and Beranek.[3]

Measurements made by Research Department are obtained with four samples of dimensions 6 ft × 4 ft (1·83 m × 1·22 m) mounted on the walls and floor of the reverberation room; the coefficients were calculated by Eyring's formula and are on occasions greater than unity owing to diffraction effects. They are directly applicable to studio use. Where materials are used in large unbroken areas lower absorption values will be found in practice. The proprietary materials mentioned are those on which the measurements were actually made, but it does not necessarily follow that these were the only materials which would be suitable for the purposes indicated.

Most of the figures are actual measured values for the stated frequencies. In some cases, however, where measurements have been carried out on sets of samples which are alike apart from the variation of one parameter, slight anomalous differences have been adjusted.

The uncertainties in the absorption coefficients in these tables should not exceed ±0·05, except where larger values are indicated.

The tables of specially constructed treatments have in some cases been divided into separate sections giving materials in current use and other materials. The figures for materials not in current use are retained for comparison where treatment in existing studios is to be replaced. The order of the sections has been arranged to correspond to the order of working in designing a new studio.

In the acoustic treatment of studios it has been found advantageous to apply absorbers in small areas, interspersing different types. This serves to improve the efficiency of absorption by introducing diffraction but also supplies a degree of diffusion to the sound field. A modular size of 2 ft × 2 ft (610 mm × 610 mm) has been found to give a reasonable compromise between the economic advantage of a large unit and the acoustic advantage of a small one.

In order to prevent axial room modes in different directions having substantially different damping and hence decay times it is necessary to arrange that the ratio of the mean absorption coefficients of any two pairs of opposing wall surfaces shall not exceed 1·4 at any frequency.

It is also important to arrange that patches of reflecting surface are not placed opposite each other without additional precautions to ensure that no rapidly periodic reflections ('flutter echo' or 'twitter') will occur. If such surfaces are placed opposite each other then they must either be in such a position that no sound source is likely to come between them (as near the ceiling of a studio), or the surfaces should be inclined to each other with a slope of at least 1 in 20.

Such reflections can occur between comparatively small areas of untreated walls particularly if the areas are flanked by transverse walls having low average absorption coefficients. Presumably the presence of the flanking wall has the effect of doubling the effective areas of the surfaces in question. Experiments have shown that such reflections can be damped by patches of absorber less than 1 m² in area.

2. Absorbing Materials

2.1 *Tables of Absorption Coefficients*

A. Structural Absorption Coefficients

These figures for the additional absorption due to vibrations of the structure are derived from the residual absorption in a room when the surface absorption has been accounted for. The actual figures vary with the size of the wall, but those quoted below have been found to give a reasonable approximation.

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Plain 9 in. (228 mm) brickwork, large walls	0·05	0·05	0·04	0·02	0·01	—	—	—
Plain 4½ in. (114 mm) brickwork	0·10	0·08	0·05	0·02	—	—	—	—
Plastered brickwork, small walls	0·08	0·11	0·05	0·05	—	—	—	—

(continued overleaf)

A. Structural Absorption Coefficients (continued)

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
3 in. (76 mm) breeze block	0·09	0·13	0·16	0·03	0·00	—	—	—
'Camden' walling†	0·27	0·24	0·12	0·06	0·02	—	—	—
Plaster on expanded metal	0·10	0·18	0·12	0·05	—	—	—	—
Board on joist floor	—	0·10	0·07	0·01	—	—	—	—
Concrete floor/walls				negligible				

† Two Celotex leaves separated by wood framing and covered with plasterboard.

B. Common Building Materials

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Brick wall	0·02	0·02	0·02	0·03	0·04	0·05	0·07	0·10
Rough concrete	0·01	0·01	0·02	0·04	0·06	0·08	0·10	0·12
Breeze blocks (unplastered)	0·13	0·13	0·37	0·85	0·65	0·56	0·55	0·51
Smooth plaster (distempered)	0·02	0·02	0·02	0·03	0·03	0·04	0·05	0·07
Smooth plaster (painted)	0·01	0·01	0·01	0·02	0·02	0·02	0·02	0·02
*1 in. (25 mm) damped plaster or thick (more than 1·5 in. (38 mm)) wood surfaces	0·13	0·11	0·07	0·05	0·05	0·04	0·04	0·04
Plaster on wood lath (normal construction, rough finish)	0·07	0·18	0·16	0·14	0·13	0·13	0·13	0·13
Hy-Rib lath and plaster: ½ in. (13 mm) plaster on lathing, 24 in. (610 mm) air space	0·09‡	0·00‡	0·03	0·03	0·03	0·03	0·02	—
½ in. (13 mm) plaster on 26G lath, 24 in. (610 mm) air space	0·10‡	0·00‡	0·03	0·03	0·03	0·03	0·02	—
1 in. (25 mm) plaster on 26G lath, 24 in. (610 mm) air space	0·09‡	0·10‡	0·03	0·03	0·03	0·03	0·02	—
1 in. (25 mm) plaster on 26G lath, 12 in. (305 mm) air space	0·20	0·00	0·03	0·03	0·03	0·03	0·02	—
Celotex building board ½ in. (13 mm)	0·04	0·06	0·10	0·15	0·21	0·26	0·26	0·29
Celotex building board (distempered)	0·04	0·06	0·10	0·15	0·19	0·21	0·21	0·22
Celotex building board with 1 in. (25 mm) air space	0·15	0·25	0·35	0·20	0·20	0·25	0·30	0·30
Oak strip floor 2 in. × 1 in. (50 mm × 25 mm) battens at 14 in. (356 mm) centres	0·06	0·11	0·29	0·11	0·12	0·07	0·07	0·07
Wood	0·05	0·06	0·07	0·09	0·10	0·10	0·12	0·15
Glass ¼ in. (6 mm) plate or thicker	—	0·03	—	0·03	—	0·03	—	—
Linoleum	0·02	0·02	0·02	0·03	0·03	0·04	0·04	0·04
Rubber flooring	0·01	0·02	0·03	0·04	0·04	0·02	0·02	—
Hardboard ⅛ in. (3 mm) on 1 in. (25 mm) battens	0·30	0·32	0·43	0·12	0·07	0·07	0·11	0·18
Wood panelling ½ in. (13 mm) on 1 in. (25 mm) battens	0·33	0·31	0·33	0·14	0·10	0·10	0·12	0·15
*Wood panelling 0·2 to 0·4 in. (5–11 mm) over air space	—	0·38	0·19	0·06	0·05	0·04	0·04	0·04

* See Introduction, paragraph 1 ‡ Estimated error $< 0{\cdot}10$

C. Air Absorption at 20°C

MV = total air absorption in ft² (where V = volume of enclosure in ft³)

	Values of M			
Relative humidity %	*1000 Hz*	*2000 Hz*	*4000 Hz*	*8000 Hz*
20	0·001	0·005	0·020	0·060
30	0·001	0·003	0·013	0·046
40	0·001	0·003	0·009	0·035
50	0·001	0·002	0·007	0·028
60	0·001	0·002	0·006	0·023
70	0·001	0·002	0·005	0·020

D. Audience, Orchestra, Seats, etc.

The absorption of the following items is given in absorption units (ft²) per item.

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
*Audience (units per person)	1·6	3·6	4·3	4·7	4·8	4·8	4·8	4·8
*Orchestra (units per person including instruments and stands)	—	4·3	9·2	12·4	15·0	14·0	12·9	—
Orchestral rostra [standard portable set, 735 ft² (68·3 m²)]	370	320	135	70	65	65	65	60
3-section settee (latex cushions)	14	21	29	36	42	47	50	50
Easi-stak padded wooden orchestra chair	—	0·5	1·3	2·7	3·8	4·6	5·0	5·0
Seats, upholstered bottoms and backs	1·3	2·59	2·86	2·95	3·43	4·0	4·17	4·2
*Tip seat, upholstered in leather, seat up	—	0·97	1·40	1·60	1·60	1·20	0·75	—
*Tip seat, bottom and back of plywood	—	0·22	0·22	0·22	0·43	0·43	0·32	—
*Theatre seat, bottom and back of plywood	—	—	—	0·14	0·24	0·41	—	—
*Grand Piano	—	2·15	—	6·45	—	5·6	—	—

The following absorption coefficients are proposed by Beranek[3] as suitable for use in large halls. The area of audience and orchestra is to include aisles up to 3·5 ft (1·07 m) in width.

*Audience (full or near-full occupation) Orchestra (including instruments and music stands)	0·39	0·54	0·66	0·78	0·85	0·83	0·75	0·71
AUDIENCE SEATING UNOCCUPIED:								
*Cloth-covered with upholstered seating	0·27	0·45	0·60	0·73	0·80	0·75	0·64	0·58
*Leather-covered with thinly upholstered seating	—	0·40	0·49	0·55	0·57	0·53	0·46	0·42

E. Hangings, Floor Coverings, and Furnishings

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Yiewsley woolcord carpet with underfelt	0·02	0·04	0·13	0·36	0·60	0·69	0·62	0·52
Haircord carpet with underfelt	0·05	0·13	0·17	0·24	0·29	0·30	0·30	0·37
*Wilton carpet with underfelt	0·04	0·08	0·22	0·51	0·64	0·69	0·71	0·70
Curtains (Drama, sailcloth, draped)	0·03	0·03	0·04	0·10	0·17	0·18	0·15	0·15
Curtains (Velour, draped)	0·05	0·06	0·31	0·44	0·80	0·75	0·65	0·60

* See Introduction, paragraph 1

(continued overleaf)

E. **Hangings, Floor Coverings, and Furnishings (continued)**

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Lightweight fabrics over 2 in. (50 mm) air space								
Stretched	0·00	0·04	0·10	0·20	0·50	0·60	0·50	0·40
Draped	0·00	0·05	0·10	0·20	0·50	0·70	0·65	0·60
Heavy fabrics over 2 in. (50 mm) air space								
Stretched	0·00	0·04	0·15	0·25	0·54	0·70	0·45	0·40
Draped	0·00	0·06	0·16	0·30	0·55	0·65	0·65	0·65

The results for fabrics vary widely with the weight and flow resistance. The above figures are for an average weave cotton or woollen material.

F. **Low-frequency Membrane Absorbers**

Recommended area: Max. 9 ft^2 (0·84 m^2) Min. 6 ft^2 (0·56 m^2)

F.1. ROOFING FELT UNITS

Single layer 3-ply roofing felt with 2 in. (50 mm) rockwool backing (density 5 lb/ft^3 (80 kg/m^3))
(1 in. (25 mm) thick rockwool for 1 in. (25 mm) air space)

Frequency (Hz)	*62*	*88*	*125*	*175*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Air space depth										
1 in. (25 mm)	0·01	0·08	0·30	0·78	0·84	0·30	0·15	0·15	0·15	0·15
3 in. (75 mm)	0·23	0·41	1·05	0·86	0·45	0·19	0·15	0·15	0·15	0·15
6 in. (152 mm)	0·43	0·93	0·91	0·47	0·55	0·30	0·15	0·15	0·15	0·15
12 in. (305 mm)	0·81	1·15	0·87	0·63	0·47	0·30	0·15	0·15	0·15	0·15
Double layer 3-ply roofing felt with 2 in. (50 mm) rockwool backing										
Air space depth										
6 in. (152 mm)	0·91	0·97	0·60	0·52	0·53	0·35	0·15	0·15	0·15	0·15
12 in. (305 mm)	0·63	0·83	0·48	0·51	0·32	0·19	0·15	0·15	0·15	0·15
Double-sided roofing felt units (absorbing area taken as cross sectional area of box). Single layer, 3-ply, no rockwool										
Air space depth										
$7\frac{1}{2}$ in. (190 mm)	0·04	0·28	0·68	0·48	0·35	0·25	0·30	0·19	0·27	0·20
F2. BONDED HARDBOARD AND ROOFING FELT UNITS										
Bonded hardboard and roofing felt absorbers with 1 in. (25 mm) rockwool backing (density 5 lb/ft^3 (80 kg/m^3))										
Air space depth										
3 in. (75 mm)	0·46	0·91	0·69	0·42	0·19	0·15	0·15	0·15	0·15	0·15
6 in. (150 mm)	0·78	0·45	0·38	0·33	0·15	0·15	0·15	0·15	0·15	0·15
F3. 'ABERDEEN' ABSORBERS										
1 in. (25 mm) Bondacoust, in front of one layer 3-ply roofing felt, over 1 in. (25 mm) Bondacoust										
Flat on wall	0·15	—	0·40	—	0·80	0·56	0·72	0·84	0·88	0·92
As above but with additional 1 in. (25 mm) air space	0·15	—	0·54	—	0·81	0·66	0·72	0·84	0·88	0·92

G. Proprietary Acoustic Tiles and Boards

Frequency (Hz)	*62*	*88*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Echostop tiles over 1 in. (25 mm) air space (with rockwool)	0·02	—	0·11	0·33	0·68	0·72	0·51	0·47	0·60
Echostop tiles over 2 ft (610 mm) air space (with rockwool) (single sample with diffusion)	0·66	—	0·74	0·75	0·67	0·66	0·62	0·58	0·65
Echostop tiles over 2 ft (610 mm) air space (without rockwool) (single sample with diffusion)	0·00	—	0·33	0·27	0·24	0·30	0·34	0·57	0·65
Solid ceiling 50% covered with 6 in. (152 mm) bonded absorbers. Echostop tiles suspended with 18 in. (460 mm) air space, 50% area of tiles with rockwool behind	0·12	0·45	0·42	0·46	0·46	0·47	0·48	0·58	0·65
Owens Corning Stria tiles, surface pricked; 7 in. (178 mm) air space	0·51	—	0·76	0·85	0·88	0·71	0·82	0·73	0·58
Owens Corning Sonofaced tiles 7 in. (178 mm) air space	0·60	—	0·83	0·88	0·86	0·76	0·83	0·70	0·48
Woodcemair 2 in. (50 mm) thick direct on wall	0·00	—	0·06	0·19	0·40	0·91	0·56	0·76	0·80
Crown Ceiling Board (PVC faced)									
Direct on wall	0·00	—	0·07	0·51	0·65	0·99	0·86	0·51	0·35
12 in. (305 mm) air space	0·42	—	0·40	0·68	0·74	0·83	0·82	0·57	0·30
Quiltiles 7 in. (178 mm) air space	0·35	—	0·36	0·75	0·86	0·77	0·85	0·72	0·55
Quiltiles (with Trayseal) 7 in. (178 mm) air space	0·50	—	0·52	0·55	0·36	0·30	0·30	0·30	0·25
Woodacoustic (wide slats, slots every other hole)									
Direct on wall	0·15	0·00	0·10	0·16	0·35	0·48	0·67	0·53	0·26
1 in. (25 mm) air space	0·05	0·05	0·13	0·36	0·40	0·50	0·70	0·59	0·32
	(Absorption peak of 0·85 – 0·90 at 2800 Hz)								
Acousti-Celotex C3 tiles on 1 in. (25 mm) battens	0·10	—	0·14	0·52	0·51	0·69	0·73	0·74	—
Acousti-Celotex C3 tiles on 1 in. (25 mm) battens (painted)	0·10	—	0·14	0·52	0·51	0·61	0·63	0·65	0·65
Acousti-Celotex C3 tiles 22 in. (559 mm) air space	0·20	—	0·29	0·44	0·56	0·57	0·63	0·61	0·49
Acoustic Planiflex 1 in. (25 mm) LDS rockwool backing	0·04	—	0·10	0·50	0·59	0·60	0·31	0·18	0·03
Burgess tiles on 1 in. (25 mm) battens $\frac{1}{8}$ in. (3 mm) dia. perforations 'A'	0·05	—	0·19	0·43	0·68	0·90	0·82	0·85	0·82
As above but $\frac{3}{32}$ in. (2 mm) dia. perforations 'B'	0·00	—	0·15	0·50	0·75	0·80	0·75	0·75	0·75
Newall's Paxtiles on 1 in. (25 mm) battens	0·07	—	0·25	0·63	0·90	1·09	1·01	0·70	0·41
Saga panelling flat on wall or on 1 in. (25 mm) battens	0·05	—	0·10	0·22	0·78	0·94	1·00	0·63	0·43

H. Porous Blankets

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
BACKING MATERIALS IN CURRENT USE								
Stillite Preformed Semi-rigid Slab SR 10 [Density 9–10 lb/ft³ (145–160 kg/m³)]								
A	0·00	0·01	0·26	0·69	1·08	1·08	1·08	1·08
B	0·00	0·09	0·36	0·74	1·08	1·08	1·08	1·08
C	0·18	0·34	0·83	0·97	1·08	1·08	1·08	1·08
D	0·27	0·68	1·04	1·03	0·86	1·08	1·08	1·08
'Biscuit Box' Absorbers 5 *in.* (127 *mm*) *deep display biscuit boxes having expanded-metal or open-weave-fabric face and* 1 *in.* (25 *mm*) *Therbloc fastened to the lid*								
(*a*) Large area 12 ft × 8 ft (3·66 m × 2·44 m) single sample test, no added diffusion	0·03	0·40	1·18	0·94	0·72	0·72	0·74	0·65
(*b*) Divided samples 6 ft × 4 ft (1·83 m × 1·22 m) patches; the very high value at 250 Hz should be viewed with caution	0·17	0·62	1·71	1·08	0·99	1·01	1·02	0·96
Grey Polyester Foam (Aeropreen Ltd) 1 in. (25 mm) thick								
Direct on walls	0·00	0·14	0·37	0·65	1·16	1·07	1·10	1·10
6 in. (152 mm) from walls	0·06	0·26	0·58	0·97	0·88	1·07	1·10	1·10
3 ft × 4 ft (0·915 m × 1·22 m) with sheets fastened round edges; centre spaced 6 in. (152 mm) from wall to simulate draping								
(*a*) Single sample test	0·16	0·05	0·23	0·44	0·63	0·59	0·69	0·74
(*b*) Divided sample test	0·16	0·05	0·22	0·55	0·86	0·89	0·89	0·76
AOP 37 Foam with PVC coating on incident face (Aeropreen Ltd) 1 in. (25 mm) thick								
Direct on walls	0·07	0·07	0·45	0·65	0·42	0·47	0·33	0·32
5 in. (125 mm) air space	0·07	0·22	0·56	0·33	0·22	0·51	0·32	0·32
OTHER BACKING MATERIALS								
Bondacoust Fibroceta Wadding 2·5 denier 1·25 lb/ft³ (20 kg/m³)								
A	0·02	0·06	0·25	0·67	0·85	0·85	0·79	0·81
C	0·07	0·23	0·56	1·02	1·02	0·91	0·97	0·88
3 in. blanket	0·12	0·37	1·16	1·29	1·08	0·92	0·90	0·93
Spun Therbloc Rigid Rockwool 14–16 lb/ft³ (224–256 kg/m³)								
A	0·03	0·08	0·32	0·76	0·86	0·87	0·97	0·92
B	0·03	0·10	0·42	0·94	1·03	0·97	0·97	0·92
C	0·10	0·30	0·93	1.20	1·01	0·99	0·97	0·92

NOTE: A = 1 in. (25 mm) backing material
B = 1 in. (25 mm) backing material + 1 in. (25 mm) air space
C = 2 in. (50 mm) backing material
D = 1 in. (25 mm) backing material + 7 in. (178 mm) air space partitioned at 2 ft × 3 ft (610 mm × 915 mm)

H. **Porous Blankets (continued)**

Frequency (Hz)		*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
1 in. (25 mm) Jones and Broadbent scrim quilt over 7½ in. (190 mm) air space, partitioned with hardboard									
Partitions 6 in. × 6 in. (152 mm × 152 mm)		0·60	0·90	0·95	0·80	0·81	0·83	0·85	0·75
Partitions 12 in. × 12 in. (305 mm × 305 mm)		0·50	0·85	0·95	0·80	0·81	0·83	0·85	0·75
Partitions 2 ft × 3 ft (610 mm × 915 mm)		0·40	0·96	0·88	0·87	0·81	0·83	0·85	0·75
Cabot's Quilt									
	A	0·05	0·15	0·21	0·35	0·79	0·86	0·59	0·79
	B	0·05	0·16	0·32	0·62	0·89	0·69	0·70	0·82
Glass Silk (Bitumen bonded)									
	A	0·06	0·18	0·30	0·58	0·76	0·78	0·60	0·56
	B	0·10	0·12	0·27	0·62	0·65	0·87	0·52	0·51
Hair Felt ⅜ in. (10 mm) carpet underlay		0·02	0·03	0·05	0·17	0·36	0·56	0·64	0·56

J. **Perforated-board Faced Absorbers**

J.1. 25% PERFORATED HARDBOARD

Frequency (Hz)		*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
BACKING MATERIALS IN CURRENT USE									
Stillite SR 10	A	0·00	0·01	0·26	0·69	1·08	0·98	0·96	0·71
	B	0·00	0·01	0·32	0·94	1·08	0·98	0·96	0·71
	C	0·11	0·27	0·87	1·00	1·08	0·98	0·96	0·71
	D	0·30	0·67	1·09	0·98	0·93	0·98	0·96	0·71
Grey polyester foam	A	0·00	0·15	0·24	0·64	1·10	0·68	0·74	0·36
Wideband absorbers: 25% *perforated hardboard, ¼ in. (6 mm) Jablon Grade B sponge,* 25% *perforated hardboard,* 1 *in. (25 mm) rockwool,* 5% *perforated hardboard,* 1 *in. (25 mm) rockwool,* 5% *perforated hardboard*									
Direct on wall		0·00	0·12	0·49	1·17	1·11	0·91	0·95	0·61
1 in. (25 mm) Bondacoust backing		0·16	0·40	1·20	1·05	0·97	0·88	0·95	0·61
'Anti carpet' absorber: 25% *slotted hardboard, ¼ in.* (6 *mm) Jablon Grade B sponge,* 1% *perforated hardboard,* 1 *in.* (25 *mm) rockwool*		0·00	0·23	0·95	0·76	0·60	0·74	0·86	0·57
OTHER BACKING MATERIALS									
Bondacoust	A	0·02	0·05	0·30	0·67	0·90	0·85	0·67	0·47
	B	0·03	0·10	0·33	0·70	0·90	0·85	0·67	0·47
	C	0·08	0·18	0·71	0·94	0·96	0·85	0·67	0·47

NOTE: A = 1 in. (25 mm) backing material
B = 1 in. (25 mm) backing material + 1 in. (25 mm) air space
C = 2 in. (50 mm) backing material
D = 1 in. (25 mm) backing material + 7 in. (178 mm) air space partitioned at 2 ft × 3 ft (610 mm × 915 mm)

(continued overleaf)

J. Perforated-board Faced Absorbers (continued)

Frequency (Hz)		*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Spun Therbloc	A	0·03	0·09	0·40	1·00	1·02	1·00	0·84	0·50
	B	0·04	0·13	0·52	1·00	1·03	1·00	0·84	0·50
	C	0·08	0·18	0·92	1·24	1·11	1·00	0·84	0·50
	D	0·23	0·54	0·98	1·00	0·98	1·00	1·00	0·70
Cabot's Quilt (20% perf. hardboard)									
	A	0·06	0·18	0·26	0·63	0·83	0·33	0·28	0·38
	B	0·05	0·10	0·32	0·78	0·93	0·64	0·53	0·43
Glass Silk (bitumen bonded) (20% perf. hardboard)									
	A	0·03	0·18	0·26	0·70	0·88	0·73	0·29	0·29
	B	0·10	0·14	0·43	0·79	0·96	0·62	0·45	0·36
J. and B. mineral wool felt type 1012									
	A	0·05	0·03	0·36	0·94	0·99	0·89	0·85	0·44

J.2. 5% PERFORATED HARDBOARD

BACKING MATERIALS IN CURRENT USE									
Stillite SR 10	A	0·00	0·01	0·34	1·14	0·90	0·49	0·30	0·15
	B	0·00	0·03	0·37	1·18	0·90	0·49	0·30	0·15
	C	0·11	0·19	0·90	1·07	0·90	0·49	0·30	0·15
	D	0·38	0·60	0·98	0·82	0·90	0·49	0·30	0·15
Air backing only									
1 in. (25 mm)		0·00	0·00	0·00	0·03	0·21	0·16	0·13	0·11
2 in (50 mm)		0·00	0·04	0·05	0·16	0·27	0·16	0·14	0·09
OTHER BACKING MATERIALS									
Bondacoust	A	0·02	0·13	0·36	0·80	0·73	0·35	0·28	0·20
	B	0·30	0·17	0·42	0·91	0·73	0·35	0·28	0·20
	C	0·10	0·28	0·91	1·21	0·73	0·35	0·28	0·20
Spun Therbloc	A	0·03	0·09	0·47	1·12	0·90	0·57	0·31	0·20
	B	0·04	0·14	0·65	1·18	0·90	0·57	0·31	0·20
	C	0·10	0·31	1·10	1·20	0·90	0·57	0·31	0·20
	D	0·35	0·50	0·88	0·99	1·00	0·82	0·44	0·20
1 in. (25 mm) J. and B. mineral wool felt type 1012									
	D	0·58	1·03	0·92	0·70	0·39	0·20	0·16	0·21
Cabot's Quilt	A	0·06	0·18	0·26	0·63	0·83	0·33	0·28	0·38
	B	0·06	0·09	0·32	0·92	0·64	0·40	0·23	0·22
Glass Silk	A	0·04	0·16	0·31	0·86	0·86	0·31	0·04	0·01
	B	0·03	0·13	0·44	0·98	0·71	0·26	0·12	0·07

NOTE: A = 1 in. (25 mm) backing material
B = 1 in. (25 mm) backing material and 1 in. (25 mm) air space
C = 2 in. (50 mm) backing material
D = 1 in. (25 mm) backing material + 7 in. (178 mm) air space partitioned at 2 ft × 3 ft (610 mm × 915 mm)

J. Perforated-board Faced Absorbers (continued)

Frequency (Hz)		*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
J.3. 0·5% PERFORATED HARDBOARD									
BACKING MATERIALS IN CURRENT USE									
Stillite SR 10	A	0·00	0·07	1·05	0·46	0·20	0·12	0·16	0·12
	B	0·05	0·07	0·80	0·46	0·20	0·12	0·16	0·12
	C	0·18	0·48	0·78	0·60	0·38	0·32	0·16	0·12
	D	0·39	0·74	0·53	0·40	0·30	0·14	0·16	0·12
'Biscuit box' absorbers									
Single sample test		0·31	1·02	0·44	0·37	0·27	0·25	0·27	0·25
Divided sample test		0·34	1·39	0·97	0·56	0·32	0·25	0·26	0·22
OTHER BACKING MATERIAL									
Spun Therbloc	D	0·50	0·63	0·95	0·80	0·46	0·28	0·30	0·33

NOTE: A = 1 in. (25 mm) backing material
B = 1 in. (25 mm) backing material + 1 in. (25 mm) air space
C = 2 in. (50 mm) backing material
D = 1 in. (25 mm) backing material + 7 in. (178 mm) air space partitioned at 2 ft × 3 ft (610 mm × 915 mm)

K. Stretched-fabric Faced Absorbers

Frequency (Hz)	*62*	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
Light open-weave fabrics (flow resistance <20 rayls)								
2 in. (50 mm) Bondacoust backing	—	0·24	0·81	1·15	1·10	0·99	0·88	0·81
2 in. (50 mm) Therbloc backing	0·01	0·34	0·98	1·25	1·00	1·00	1·00	0·88
2 in. (50 mm) air space	—	0·02	0·11	0·22	0·41	0·60	0·30	0·32
Light close-weave fabrics (flow resistance >100 rayls)								
2 in. (50 mm) Bondacoust	0·05	0·24	0·64	1·26	0·83	0·57	0·50	0·37
2 in. (50 mm) Therbloc	0·05	0·27	1·07	1·24	0·96	0·75	0·52	0·38
2 in. (50 mm) air space	—	0·06	0·10	0·20	0·47	0·40	0·39	0·39
Heavy open-weave fabrics (flow resistance <20 rayls)								
2 in. (50 mm) Bondacoust	—	0·29	0·79	1·20	1·16	1·01	0·97	0·68
2 in. (50 mm) Therbloc	0·03	0·30	1·05	1·25	1·08	1·11	0·96	0·81
2 in. (50 mm) air space	—	0·04	0·14	0·27	0·51	0·70	0·42	0·41
Heavy close-weave fabrics (flow resistance >100 rayls)								
2 in. (50 mm) Bondacoust	—	0·32	1·08	1·27	0·96	0·85	0·82	0·70
2 in. (50 mm) Therbloc	—	0·33	1·12	1·12	0·95	0·88	0·79	0·70
2 in. (50 mm) air space	—	0·04	0·20	0·68	0·83	0·81	0·65	0·61

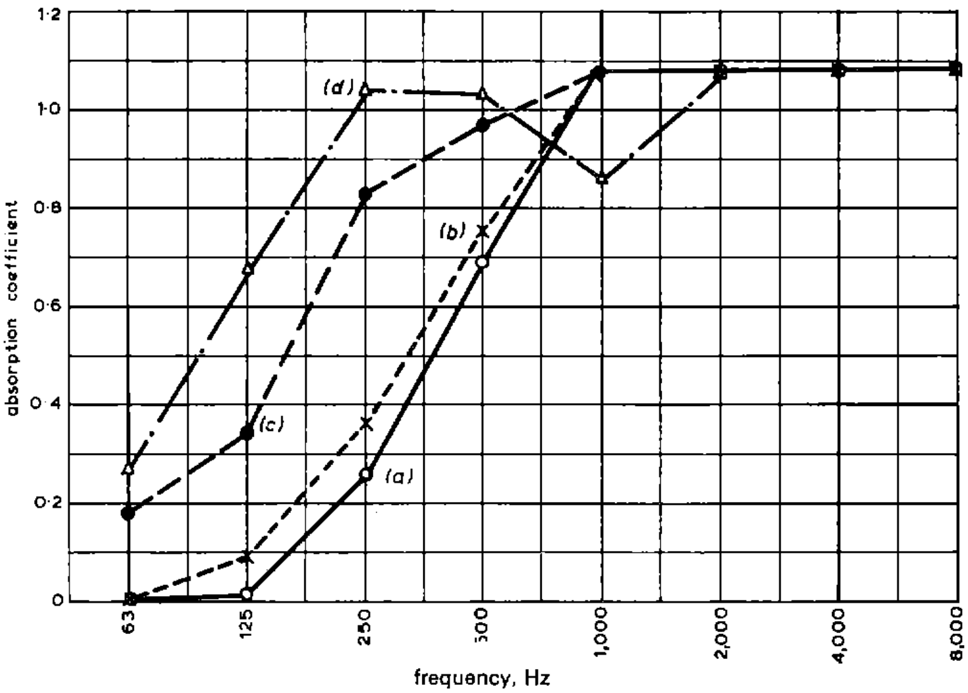

Fig. 1 — Absorption coefficient of Stillite Mineral Wool SR 10, *thicknesses* 1 *in.* (25 *mm*) *and* 2 *in.* (50 *mm*). *No cover*

(*a*) 1 in. (25 mm) thick. No air space
(*b*) 1 in. (25 mm) thick. 1 in. (25 mm) air space
(*c*) 2 in. (50 mm) thick. No air space
(*d*) 1 in. (25 mm) thick. 7 in. (178 mm) air space

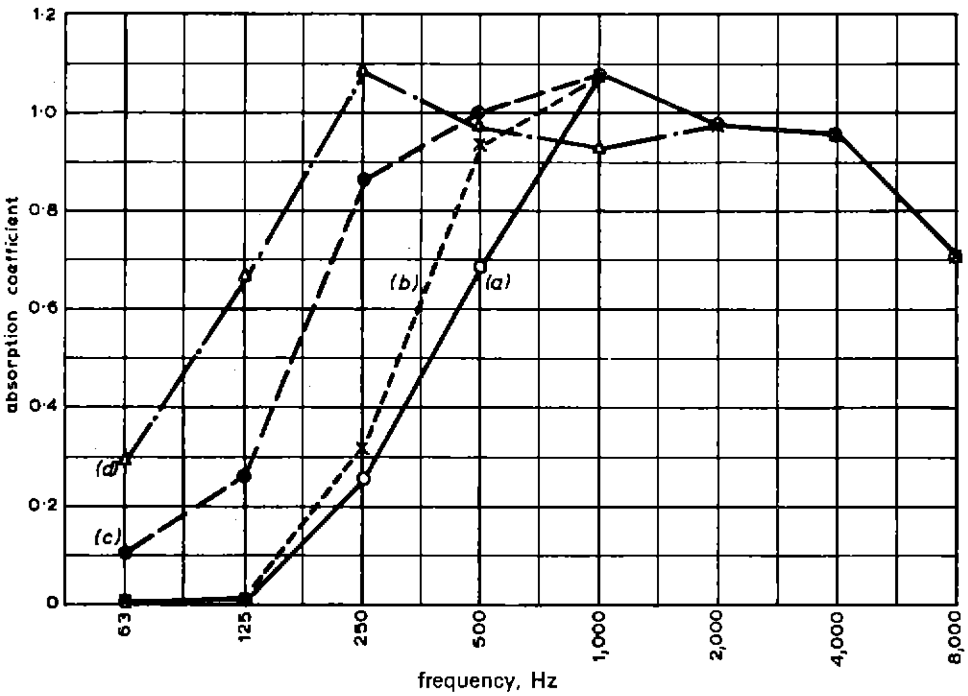

Fig. 2 — Absorption coefficient of Stillite Mineral Wool SR 10, *thicknesses* 1 *in.* (25 *mm*) *and* 2 *in.* (50 *mm*). 25 % *perforated hardboard cover*

(*a*) 1 in. (25 mm) thick. No air space
(*b*) 1 in. (25 mm) thick. 1 in. (25 mm) air space
(*c*) 2 in. (50 mm) thick. No air space
(*d*) 1 in. (25 mm) thick. 7 in. (178 mm) air space

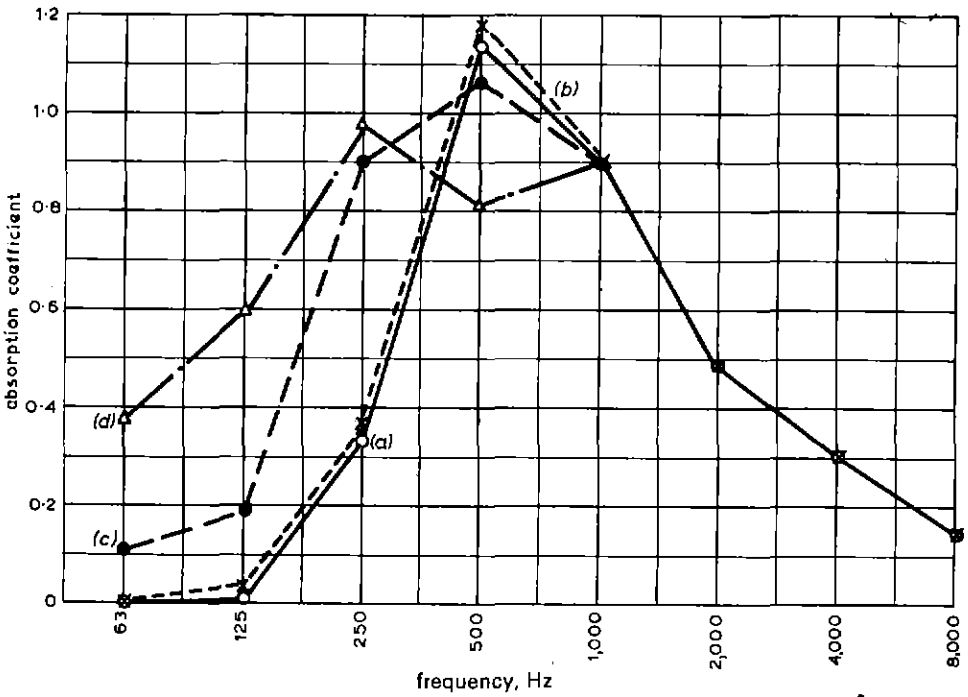

Fig. 3 — *Absorption coefficient of Stillite Mineral Wool SR* 10, *thicknesses* 1 *in.* (25 *mm*) *and* 2 *in.* (50 *mm*). 5 % *perforated hardboard cover*

(*a*) 1 in. (25 mm) thick. No air space
(*b*) 1 in. (25 mm) thick. 1 in. (25 mm) air space
(*c*) 2 in. (50 mm) thick. No air space
(*d*) 1 in. (25 mm) thick. 7 in. (178 mm) air space

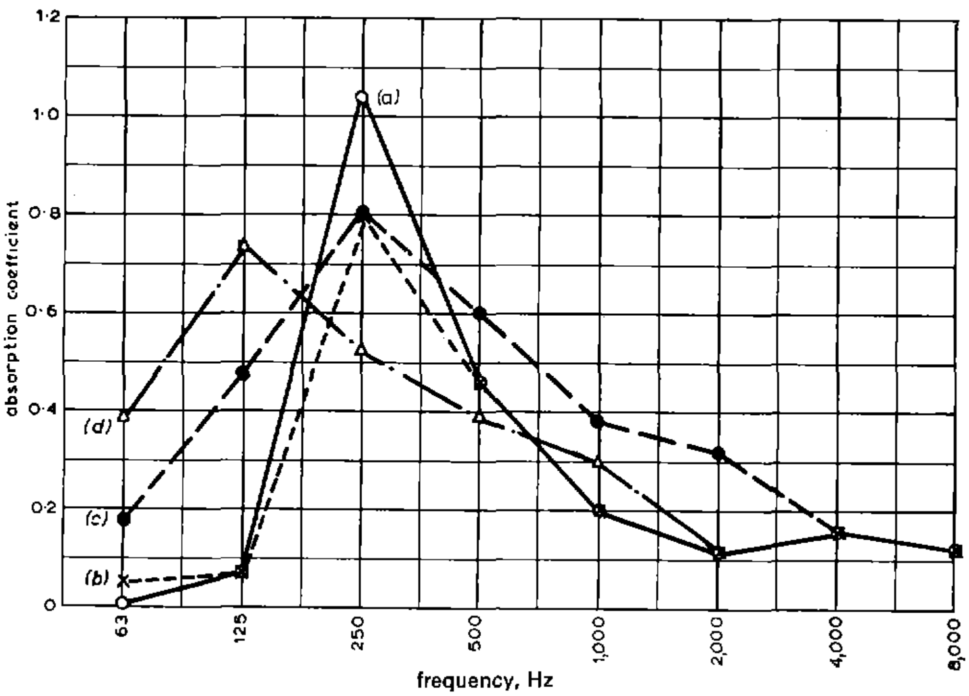

Fig. 4 — *Absorption coefficient of Stillite Mineral Wool SR* 10, *thicknesses* 1 *in.* (25 *mm*) *and* 2 *in.* (50 *mm*). 0·5 % *perforated hardboard cover*

(*a*) 1 in. (25 mm) thick. No air space
(*b*) 1 in. (25 mm) thick. 1 in. (25 mm) air space
(*c*) 2 in. (50 mm) thick. No air space
(*d*) 1 in. (25 mm) thick. 7 in. (178 mm) air space

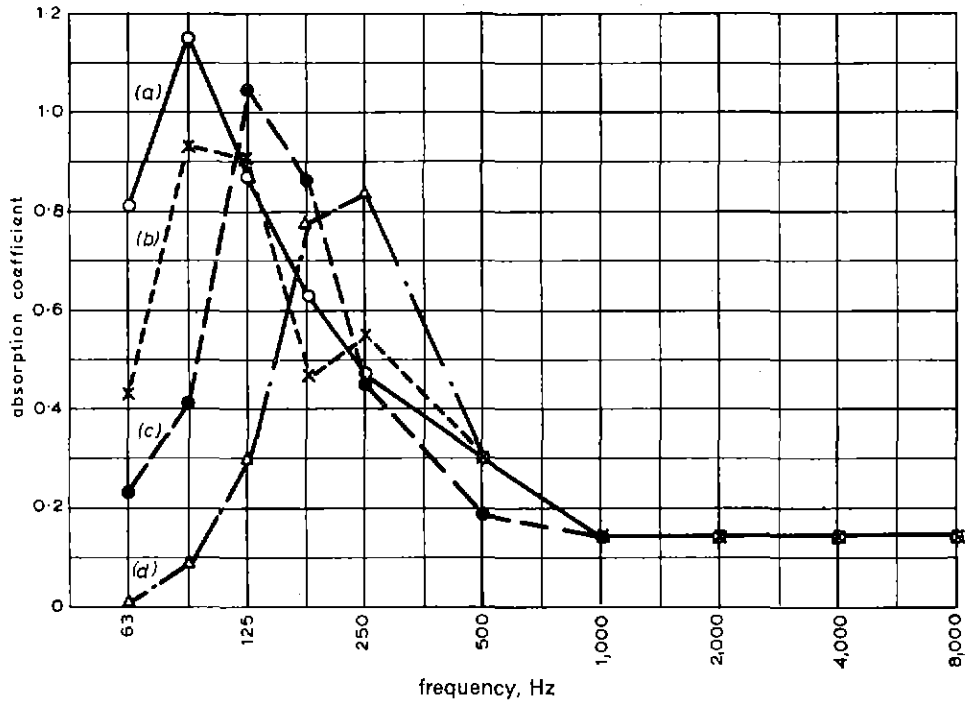

Fig. 5 — Absorption coefficient of single layer 3-ply roofing felt units

(*a*) 12 in. (305 mm) air space
(*b*) 6 in. (152 mm) air space
(*c*) 3 in. (75 mm) air space
(*d*) 1 in. (25 mm) air space

3. Calculation of Reverberation Time

The relationship between the reverberation time of a room, its volume and the absorption of its surface was given in a simple form by Sabine[4]

$$T = \frac{0 \cdot 049V}{S\bar{\alpha} + MV}$$

where T = Reverberation Time in seconds
V = Volume of room (ft^3)*
S = Total surface area of room (ft^2)*
M = Air absorption constant (ft^{-1})* listed in Section 2.1C

and $\bar{\alpha}$ is the mean absorption coefficient of all the surfaces of the room, normally calculated from the equation

$$S\bar{\alpha} = \Sigma\alpha_i S_i$$

over all the types of surface.

Sabine's formula has the advantage of simplicity and ease of application. It is useful for quick calculations on the effects of minor modifications to treatment but is only accurate for very reverberant rooms.

Where the mean coefficient of the surfaces is more than 0·1 Sabine's formula gives significantly high results and the error increases rapidly as the mean coefficient rises.

Eyring[5] derived a more accurate formula, taking into account the fact that the sound is absorbed only when a wavefront reaches a boundary and not continuously throughout the volume as assumed by Sabine.

This formula is $$T = \frac{0 \cdot 049V}{-S \log_e(1 - \bar{\alpha}) + MV}$$

It will be noticed that this formula differs from that of Sabine by the substitution of $-\log_e(1 - \bar{\alpha})$ for $\bar{\alpha}$.

Table 1 gives values of $-\log_e(1 - \bar{\alpha})$ for values of $\bar{\alpha}$ up to 0·50.

4. Preferred Reverberation Times

4.1. *Preferred Reverberation Times of Sound Studios*

The graphs shown in Fig. 6 give the preferred variation of mid-frequency reverberation time with volume for a variety of types of sound studio. Given the design reverberation time the acoustic treatment will be selected to achieve this value at all frequencies.

Talks studios will generally have volumes between 1000 and 5000 ft^3 (28·3–143 m^3) and the design reverberation times will lie on curve (*a*) in Fig. 6.

Symphonic music studios have volumes above 20,000 ft^3

* For the benefit of those who wish to carry out calculations in metric units instead of British, it should be noted that the constant in the numerator of both equations should then be 0·169 and M should become 3·28 M.

TABLE 1

Values of $-\log_e (1 - \bar{\alpha})$

$\bar{\alpha}$	0	0·001	0·002	0·003	0·004	0·005	0·006	0·007	0·008	0·009
0·00										
0·01	}	Equal to $\bar{\alpha}$ within 0·001								
0·02										
0·03	0·030	0·032	0·033	0·034	0·035	0·036	0·037	0·038	0·039	0·040
0·04	0·041	0·042	0·043	0·044	0·045	0·046	0·047	0·048	0·049	0·050
0·05	0·051	0·052	0·053	0·054	0·055	0·057	0·058	0·059	0·060	0·061
0·06	0·062	0·063	0·064	0·065	0·066	0·067	0·068	0·069	0·070	0·072
0·07	0·073	0·074	0·075	0·076	0·077	0·078	0·079	0·080	0·081	0·082
0·08	0·083	0·085	0·086	0·087	0·088	0·089	0·090	0·091	0·092	0·093
0·09	0·094	0·096	0·097	0·098	0·099	0·100	0·101	0·102	0·103	0·104
0·10	0·105	0·107	0·108	0·109	0·110	0·111	0·112	0·113	0·114	0·115
0·11	0·117	0·118	0·119	0·120	0·121	0·122	0·123	0·124	0·126	0·127
0·12	0·128	0·129	0·130	0·131	0·132	0·134	0·135	0·136	0·137	0·138
0·13	0·139	0·140	0·142	0·143	0·144	0·145	0·146	0·147	0·149	0·150
0·14	0·151	0·152	0·153	0·154	0·155	0·157	0·158	0·159	0·160	0·161
0·15	0·163	0·164	0·165	0·166	0·167	0·168	0·170	0·171	0·172	0·173
0·16	0·174	0·176	0·177	0·178	0·179	0·180	0·182	0·183	0·184	0·185
0·17	0·186	0·188	0·189	0·190	0·191	0·192	0·194	0·195	0·196	0·197
0·18	0·198	0·200	0·201	0·202	0·203	0·205	0·206	0·207	0·208	0·209
0·19	0·211	0·212	0·213	0·214	0·216	0·217	0·218	0·219	0·221	0·222
0·20	0·223	0·224	0·225	0·226	0·227	0·229	0·231	0·232	0·233	0·234
0·21	0·236	0·237	0·238	0·240	0·241	0·242	0·243	0·245	0·246	0·247
0·22	0·248	0·250	0·251	0·252	0·253	0·255	0·256	0·257	0·259	0·260
0·23	0·261	0·263	0·264	0·265	0·267	0·268	0·269	0·270	0·272	0·273
0·24	0·274	0·276	0·277	0·278	0·280	0·281	0·282	0·284	0·285	0·286
0·25	0·288	0·289	0·290	0·292	0·293	0·294	0·296	0·297	0·298	0·300
0·26	0·301	0·302	0·304	0·305	0·307	0·308	0·309	0·311	0·312	0·313
0·27	0·315	0·316	0·317	0·319	0·320	0·322	0·323	0·324	0·326	0·327
0·28	0·329	0·330	0·331	0·333	0·334	0·335	0·337	0·338	0·340	0·341
0·29	0·343	0·344	0·345	0·347	0·348	0·350	0·351	0·352	0·354	0·355
0·30	0·357	0·358	0·360	0·361	0·362	0·364	0·365	0·367	0·368	0·370
0·31	0·371	0·373	0·374	0·375	0·377	0·378	0·380	0·381	0·383	0·384
0·32	0·386	0·387	0·389	0·390	0·392	0·393	0·395	0·396	0·397	0·399
0·33	0·400	0·402	0·403	0·405	0·406	0·408	0·409	0·411	0·413	0·414
0·34	0·416	0·417	0·419	0·420	0·422	0·423	0·425	0·426	0·428	0·429
0·35	0·431	0·432	0·434	0·435	0·437	0·439	0·440	0·442	0·443	0·445
0·36	0·446	0·448	0·449	0·451	0·453	0·454	0·456	0·457	0·459	0·460
0·37	0·462	0·464	0·465	0·467	0·468	0·470	0·471	0·473	0·475	0·476
0·38	0·478	0·480	0·481	0·483	0·484	0·486	0·488	0·489	0·491	0·493
0·39	0·494	0·496	0·498	0·499	0·501	0·503	0·504	0·506	0·508	0·509
0·40	0·511	0·513	0·514	0·516	0·518	0·519	0·521	0·523	0·524	0·526
0·41	0·528	0·529	0·531	0·533	0·534	0·536	0·538	0·540	0·541	0·543
0·42	0·545	0·546	0·548	0·550	0·552	0·553	0·555	0·557	0·559	0·560
0·43	0·562	0·564	0·566	0·567	0·569	0·571	0·573	0·574	0·576	0·578
0·44	0·580	0·582	0·583	0·585	0·587	0·589	0·591	0·592	0·594	0·596
0·45	0·598	0·600	0·602	0·604	0·605	0·607	0·609	0·611	0·613	0·614
0·46	0·616	0·618	0·620	0·622	0·623	0·625	0·627	0·629	0·631	0·633
0·47	0·635	0·637	0·639	0·641	0·642	0·644	0·646	0·648	0·650	0·652
0·48	0·654	0·656	0·658	0·660	0·662	0·664	0·666	0·667	0·669	0·671
0·49	0·673	0·675	0·677	0·679	0·681	0·683	0·685	0·687	0·689	0·691
0·50	0·693	0·695	0·697	0·699	0·701	0·703	0·705	0·707	0·709	0·711

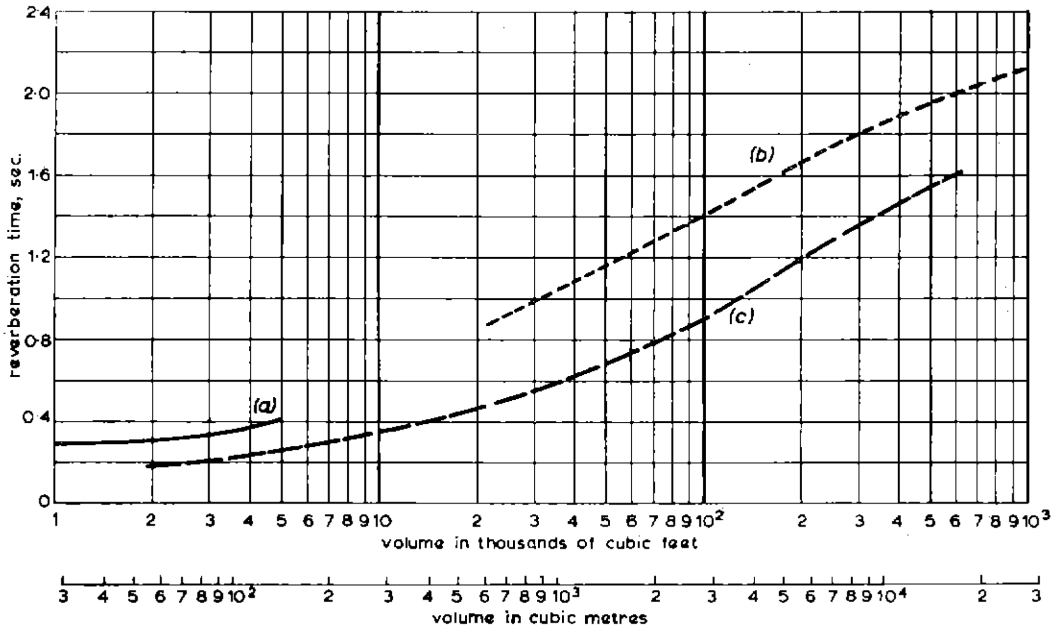

Fig. 6 — Optimum reverberation time of sound studios

(*Values represent maximum reverberation time in the frequency range* 500–2000 *Hz. Based on preferred BBC studios*)

(*a*) Studios for speech (*b*) Music studios (*c*) Other studios (see text)

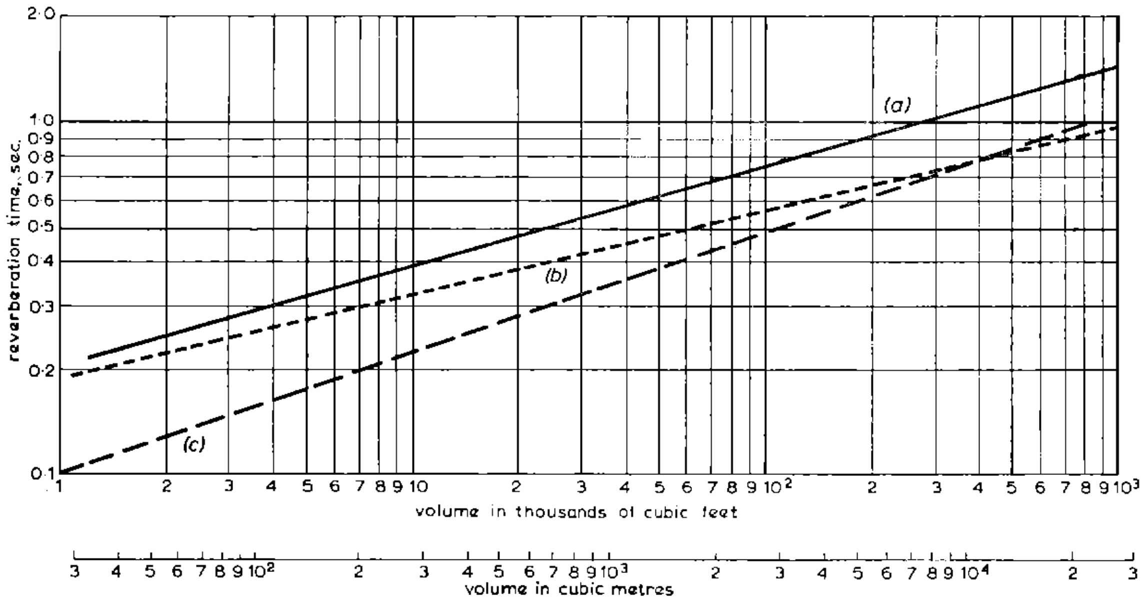

Fig. 7 — Optimum reverberation time of television studios

(*Values represent maximum reverberation time in the frequency range* 500–2000 *Hz*)

(*a*) Highest acceptable reverberation time (*b*) Optimum reverberation time (*c*) Lowest practicable reverberation time

(566 m^3) and the design reverberation times with an orchestra of suitable size for the studios will lie on curve (*b*) in Fig. 6. Studios for chamber music will lie on the same curve.

Drama studios are generally of a live-end dead-end construction. The total volume is generally between 2000 and 30,000 ft^3 (57–850 m^3) and the reverberation time of the whole studio will be on the appropriate section of curve (*c*) in Fig. 6. A large proportion of the treatment will be concentrated in the dead end and the middle and high frequency reverberation time is usually designed to be about 0·2–0·3 sec. The live end will have appropriately longer reverberation times than the values in the curve. In addition a drama complex will include areas giving very live (echo room) and very dead (anechoic) conditions.

A new class of dead music studios has been developed for 'pop' and dance music requiring acoustical separation between groups of musicians; the producer is thus given the maximum freedom to manipulate the studio outputs. Volumes of these studios lie between 10,000 and 100,000 ft^3 (283–2830 m^3) and the reverberation time variation is generally represented by curve (*c*) although the smaller studios often have lower reverberation times.

Variety or Light Entertainment studios which are required to accommodate audiences are usually converted theatres. Volumes are between 100,000 and 300,000 ft^3 (2830–8500 m^3) and the reverberation times are given by curve (*c*) in Fig. 6.

General purpose studios of volumes between 3000 and 30,000 ft^3 (85–850 m^3) have reverberation times given by curve (*c*).

Listening rooms and control rooms should not be very dissimilar from the average conditions encountered in private houses. According to Gilford[6] the longest reverberation time which can be permitted without seriously affecting judgement of quality is about 0·4 secs and this approximates to the results found for well-furnished living rooms. All listening and control rooms are therefore designed to have a reverberation time of 0·4 sec up to 250 Hz falling steadily above this frequency to 0·3 sec at 8000 Hz.

4.2. *Preferred Reverberation Times of Television Studios*

The graph shown in Fig. 7 gives the normal design variation of reverberation time with volume for television studios. The limits between which the design figures may fall are shown for different types of usage.

Sound control rooms attached to television studios should have reverberation characteristics similar to those specified above for control cubicles of sound studios. Production and lighting control rooms should be made as dead as is practicable to improve speech intelligibility between staff.

The preferred reverberation times described above are for guidance only and may be modified to meet particular cases.

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